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U. S. ARMY
TRANSPORTATION RESEARCH COMMAND
FORT EUSTIS, VIRGINIA

PERSONNEL RESTRAINT SYSTEMS STUDY

BASIC CONCEPTS

December 1962

Contract DA-44-177-TC-802

TCREC Technical Report 62-94

prepared by :

AVIATION CRASH INJURY RESEARCH
PHOENIX, ARIZONA
A DIVISION OF
FLIGHT SAFETY FOUNDATION, INC.
NEW YORK, NEW YORK
FSF

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This report was prepared by Aviation Crash Injury Research, a division of the Flight Safety Foundation, Inc., under the terms of Contract DA 44-177-TC-802. Views expressed in the report have not been reviewed or approved by the Department of the Army; however, conclusions and recommendations contained therein are concurred in by this Command.

The Transportation Materiel Command, St. Louis, Missouri, provided the contract funds required to perform a study designed to investigate the feasibility and practicability of attaching crew restraint systems in Army aircraft to basic structure rather than to the crew seat as has been the standard practice. This report is the first of four reports planned to complete the study. The other three reports will cover the detailed restraint system modifications recommended on the AC-1, HC-1, and HU-1 series aircraft.

FOR THE COMMANDER:

1/LT

FOR KENNETH B. ABEL
Captain USA
Adjutant

APPROVED BY:

WILLIAM J. NOLAN
USATRECOM Project Engineer

Task 9R95-20-001-01
Contract DA 44-177-TC-802
December 1962

PERSONNEL RESTRAINT SYSTEMS STUDY

BASIC CONCEPTS

Crash Injury Evaluation
AvCIR 62-12

Prepared by
Aviation Crash Injury Research
A Division of
Flight Safety Foundation, Inc.
2871 Sky Harbor Blvd.
Phoenix, Arizona

for

U. S. ARMY TRANSPORTATION RESEARCH COMMAND
FORT EUSTIS, VIRGINIA

By

Joseph L. Haley, Jr.

Appendix I

by

James P. Avery, Ph. D.

CONTENTS

CONTENTS (Cont'd.)

SUMMARY

This report covers the basic concepts, applicable to all U. S. Army aircraft, that are pertinent to a personnel restraint systems study. Man's tolerable limits to decelerative loads are reviewed and related to the existing restraint harnesses currently being used in Army aircraft. The magnitude of decelerative loads to which airframes of various aircraft have been dynamically tested, while still maintaining a livable volume in the cabin, are also reviewed and it is noted that man's limits are, in general, higher than airframe limits.

Several practical harness configurations are discussed and the load distribution between the various components of the harness are explored and design strength values are recommended. The dynamic strength of restraint systems is also discussed and related to the static strength.

CONCLUSIONS

It is concluded that:

1. Forward-facing personnel, restrained by lap belt and shoulder straps only, tend to "submarine" under the lap belt during deceleration; the "submarining" can cause serious injuries. The addition of a lap belt tiedown (a vertical attachment to prevent upward movement of the lap belt) will reduce the "submarining" and improve the restraint provided by the existing lap belt and shoulder straps.

2. The optimum width of a lap belt is considered to be 2.5-3.0 inches for all aircraft passengers; this width insures minimum webbing pressure consistent with comfort.

3. The standard double-strap shoulder harness should be increased in width from the existing 1.72 inches to a width of 2.0 inches. This width insures minimum webbing pressure consistent with comfort. The increased shoulder strap width will hopefully reduce the physiological effects of deceleration.

4. The optimum angle of the lap belt, measured in respect to the seat cushion, is 45-55 degrees.

5. Side-facing personnel need upper torso restraint to insure that decelerative forces are applied perpendicular to the spine; however, the addition of shoulder straps for personnel seated on existing understrength troop seats is not considered worthwhile, because failure of these seats will nullify the benefits of the shoulder straps.

6. The side-facing restraint harness, with the diagonal strap and arm band, illustrated in Figure 8 of this report, offers several advantages over the standard, double-shoulder strap, forward-facing harness.

7. Shoulder straps for forward-facing and side-facing personnel should pass over the shoulders at an angle of zero degrees, or greater, up to 30 degrees from a horizontal plane.

8. The type G-1, 1800-pound shoulder harness (dwg-AF50D3770) is understrength and permits excessive elongation.

9. The following systems, as discussed in this report, are considered to be worthy of further tests and evaluation. These restraint systems include a dual-strap inertia reel, which offers several advantages over the existing single strap reel.

   a. Restraint Harness "A" features a "snap-in", quick-release buckle attached to inverted "V" straps.

   b. Restraint Harness "C" features diagonally crossed shoulder straps, a "snap-in" quick-release buckle, and thigh straps.

   c. Restraint Harness "D" features standard military shoulder straps and lap belt with inverted "V" straps added.

10. Harness components should be designed to withstand the following loads for a minimum of 0.1 second:

Shoulder Straps	-	4000 lb
Lap Belt	-	6000 lb
Inverted "V" Strap	-	3000 lb
Belt Tiedown Strap	-	2500 lb

11. Existing lap belts and shoulder straps in Army aircraft are described by ten military specifications and fifteen (USAF and Navy) drawings; it would seem logical to select one specification or drawing to govern all belt and shoulder strap procurement in future designs.

12. Inertia reels should be dynamically tested to determine their resistance to rapid extension rates as expected in actual crashes, and the automatic inertia locking adjustment should be changed from 2-3G to 2.5-3.5G to insure against inadvertant actuation.

13. The entire "tiedown chain", which includes the lap belt, the shoulder harness, the seat, the floor, and all related

anchorages, should be compatible with the restraint harness design. In order to make the various components of the "tiedown chain" equal to the known human tolerance limits, and to the apparent crash limits of aircraft structures, the following strength values should be considered for use by restraint system designers:[30]

Transverse direction (perpendicular to the spine) -
45G for 0.10 second, and
25G for 0.20 second

Vertical direction (headward) - 25G* for 0.10 second

14. The failure strength of restraint system designs which utilize ductile materials can be considerably higher where "limit analysis" and ultimate design concepts are used in preference to traditional elastic stress analysis, in which plastic deformation is avoided. Limit analysis and ultimate design are dependent upon plastic deformations.

15. The use of ductile materials in the "tiedown chain" is desirable in that plastic deformations tend to dampen short-duration peak loads such as actually experienced in accidents.

---

* The 25G limit is based upon the human limits as noted in Figure 1 of this report; minor injuries are expected in the neighborhood of this value, but the injuries should not be serious enough to prevent an escape from the aircraft. Since the vertical (headward) decelerations in survivable aircraft accidents, particularly with VTOL aircraft, will often exceed this value, some method of energy absorption should be provided in seat designs in order that decelerative loads do not exceed 25G.

RECOMMENDATIONS

It is recommended that:

1. The single, lap belt tiedown be installed on existing, forward-facing restraint harnesses.

2. A lap belt width of 2.5 inches be adopted as a minimum standard for all passengers.

3. The point of lap belt centerline intersection with the seat cushion be changed from the seat back to a point 3 inches forward of the seat back in order to maintain a minimum angle of 45 degrees to the cushion.

4. A side-facing restraint harness with a diagonal shoulder strap and arm band be further evaluated.

5. Shoulder straps not be installed on existing understrength troop seats.

6. The type G-1 shoulder harness (1800-pound strength) not be used in new aircraft designs.

7. The shoulder strap guide, or attachment, be located a minimum of 26 inches above the seat cushion for troop seats and crew seats. The shoulder straps can pull off higher than this point, up to an angle of 30 degrees to the horizontal.

8. The following systems be further tested and evaluated.

    a. Restraint Harness "A", which features a "snap-in" quick-release buckle attached to inverted "V" straps.

    b. Restraint Harnes. "C", which features diagonally crossed shoulder straps, a "snap-in" quick-release buckle, and thigh straps.

    c. Restraint Harness "D", which features standard military shoulder straps and lap belt with inverted "V" straps installed.

9. Harness components be designed to withstand the following loads for a minimum of 0.10 second:

Shoulder Straps	-	4000 lb
Lap Belt	-	6000 lb
Inverted "V" Strap	-	3000 lb
Belt Tiedown Strap	-	2500 lb

10. One specification or drawing be used to cover lap belt and shoulder strap procurement.

11. Inertia reels be dynamically tested to determine their resistance to rapid extension rates as expected in actual crashes, and the automatic actuation device be increased to a 2.5-3.5G deceleration value.

12. All the components of the passengers' "tiedown chain" be designed to withstand the following load factors:

    Transverse direction (perpendicular to the spine) -
    45G for 0.10 second, and

    25G for 0.20 second

    Vertical direction (headward) - 25G for 0.10 second

    Note: G values in the transverse direction are to be used with a 200-pound, 95 percentile man; however, the 25G value in the vertical direction is to be used with a 164-pound, 50 percentile man to insure that spinal column loads are not excessive for low percentile personnel. Loads in the vertical direction must be attenuated to the 25G value by some type of energy-absorbing device.

BACKGROUND

Accident experience indicates that survival in aircraft accidents is dependent upon five general factors, which are defined as follows:

1. Crashworthiness: The ability of basic aircraft structure to provide a protective "shell" around occupants during potentially survivable impact conditions. *

2. Tiedown Chain: All the components of the occupant's restraint system, including the seat belt, the shoulder harness, the seat structure, the floor, and all related anchorages.

3. Occupant Environment: The injury potential of all objects and structure within the occupant's striking range.

4. Transmission of Crash Force: The manner in which crash forces are transmitted (magnified or attenuated) by intervening structure to the occupants.

5. Postcrash Factors: Postcrash fire, emergency evacuation, ditching characteristics, etc.

Failure of the tiedown chain has been the major cause of unnecessary injuries and fatalities in numerous aircraft accidents, some of which are covered in References 16, 25, 26, 28, and 35. This is unfortunate, since the tiedown chain is the easiest to control of the five factors defined above. Even if postcrash fire or ditching is considered, improved restraint can mean the difference between life or death,

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* Definition of "Survivable Impact Conditions" - Force vectors as experienced by the occupant through his seat and restraint system, which do not exceed the survivable limits of deceleration and which leave immediate environmental structure substantially intact. The Aircraft Transport Association of America definition of a survivable accident: "An accident in which some portion of the passenger cabin remains substantially intact, although other portions may have been destroyed by impact but not by fire."

since extrication from a burning or submerged aircraft is tremendously enhanced if no prior injury or debilitation has occurred (Reference 18).

The objective of this restraint systems study is to explore the feasibility and practicability of improving seat belt and shoulder harness installations in Army aircraft, and thereby to reduce the severity and frequency of injuries and fatalities in potentially survivable accidents.

The study has been conducted in two areas. The first is the design and strength of a personnel restraint harness (seat belt, shoulder harness, and tiedown straps). The second area is the manner in which the personnel restraint system is attached in each of the specific aircraft studied. The results and recommendations regarding the personnel restraint harness study are all contained in this report and will not be repeated, because the concepts are applicable to all of the aircraft studied. The manner in which the restraint systems are attached in the specific aircraft studied is covered in separate reports for each of the aircraft.

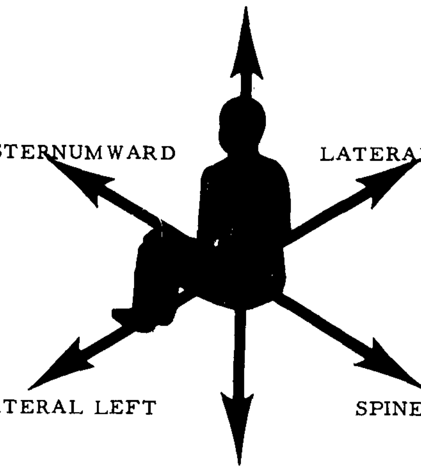
Throughout this report, the term (G) will be used to indicate the ratio of forces acting on a body to its own gravitational force (weight). The (G) term can be associated with dynamic or static forces because force magnitude is not related to time. Thus, the absolute value of a "G" force may be the same for static or dynamic conditions, but the effects of the force on the body or structure involved may be quite different. The effects of dynamic loads on structures are discussed further in the section on "Dynamic Strength of Restraint Systems" in the latter part of this report.

In attempting to define the design requirements for an optimum restraint system, and in exploring the various personnel restraint harness concepts, decelerative limits for both personnel and aircraft are discussed.

DECELERATION LIMITS

The design of a restraint harness must be guided by human decelerative limits and by the magnitude of the decelerations anticipated in potentially survivable accidents. A 200G restraint harness, for example, would obviously be bulky and heavy and it would also be impractical because the human body could not survive this magnitude of deceleration for the durations generally associated with a potentially survivable accident.

Since force direction is a critical factor in human limits to impact decelerations, the deceleration vectors used in this report are defined below:



Direction of Decelerative Force

VERTICAL Headward (+ G)
(Eyeballs down)
Tailward (-G)
(Eyeballs up)

TRANSVERSE
Lateral Right - Eyeballs left
Lateral Left - Eyeballs right
Sternumward - Eyeballs in
Spineward - Eyeballs out

Note: The decelerative force on the body acts in the same direction as the arrows.

Occupant Limits

Man's deceleration limits, as presently known, are illustrated in Figures 1 and 2. In these figures, it will be noted that the headward limits are less than one-half of the transverse limits: i.e., the voluntary headward limits up to approximately 0.04 second are approximately 17G and decrease thereafter with an increased duration of deceleration, whereas the transverse limits are approximately 45G up to 0.05 second, and they also decrease with an increase in duration.

Decelerative limits in the tailward direction are specified in Reference 7, page 86. These data indicate that voluntary limits are only 8G for 0.02 second duration, but the severe injury limits are indicated at 50G for 0.11 second duration. The data further indicate that 15G could be tolerated for 0.10 second without injury.

The caption on Figure 2 indicates that maximum body support was used, but actually the support consisted of 3-inch-wide shoulder

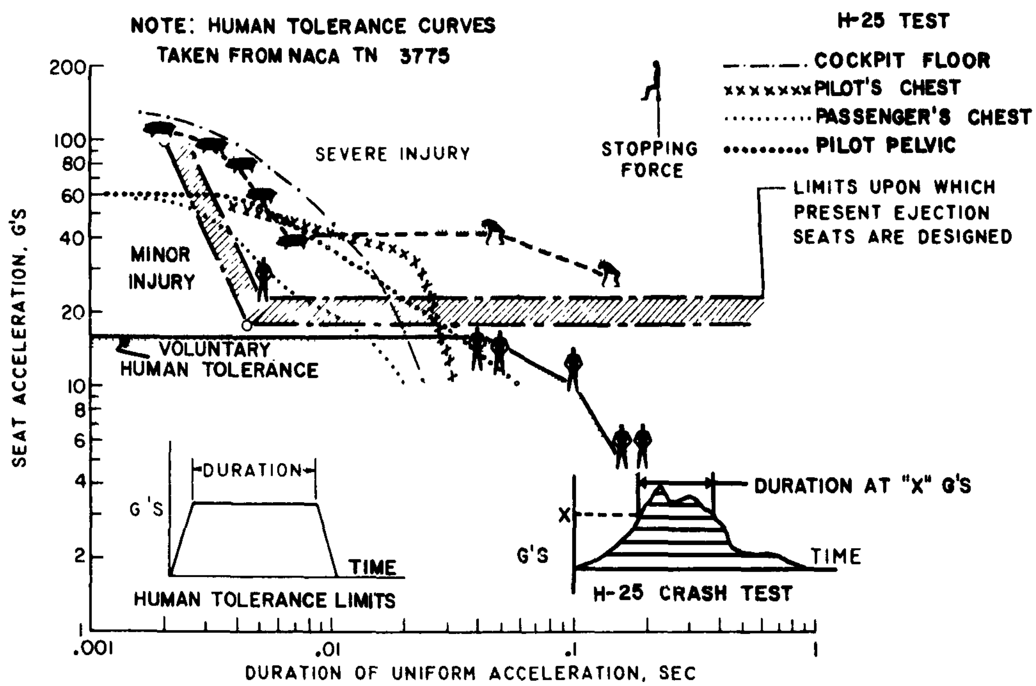


Figure 1. Tolerance to Acceleration Parallel to Spine When Using Seat Belt and Shoulder Harness Compared With H-25 Crash Test Data.

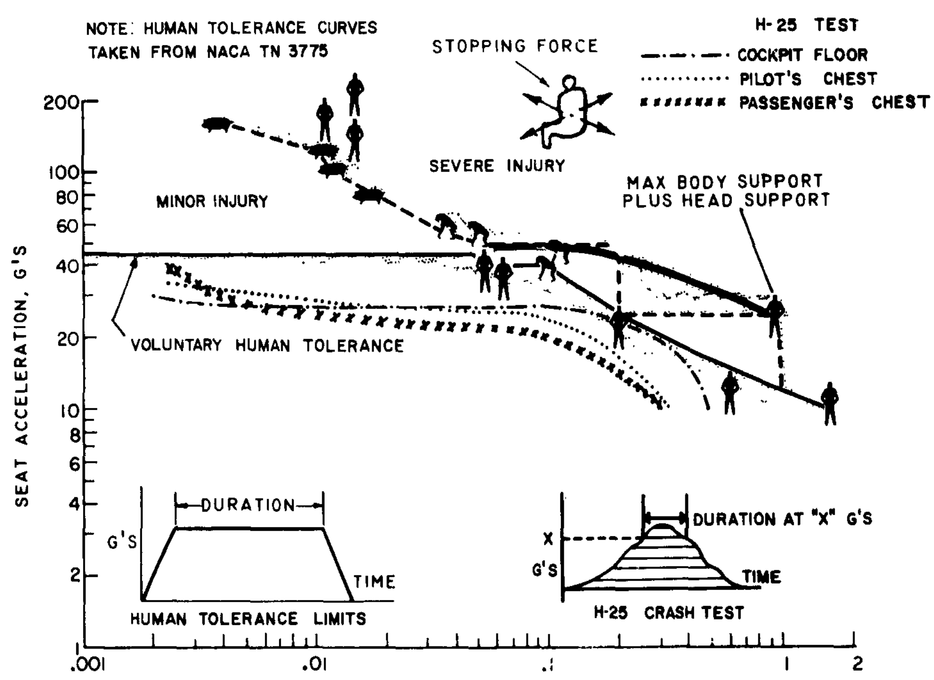


Figure 2. Tolerance to Acceleration Perpendicular to the Spine When Using Maximum Body Support Compared With H-25 Crash Test Data.

harness, lap belt, and inverted "V" straps.[2] True maximum support would consist of a harness which distributes load evenly over the entire body. The "maximum support" referred to in Figure 2 is illustrated by harnesses A, C, and D of this report.

With this type harness installed, the human tolerance limits in the transverse direction indicate that 45G's can be sustained for 0.10 second with little or minor injury and that 25G's can be sustained for 0.20 second without injury. It can be seen in Table 1 that these deceleration pulses are, in general, greater than the deceleration pulses measured in full-scale crash tests; therefore, these values are recommended for restraint system designs.

The helicopter crash test data of Table 1, lines 16-20, which tests simulate potentially survivable accidents, indicate that headward decelerations are generally higher than transverse decelerations. This fact dictates that some type of energy-absorption system, material, or device be incorporated to protect the occupants against vertical (headward) decelerations greater than 25G, which is the upper limit of present ejection seat designs (Figure 2). The data of Figure 2 indicate that approximately 0.10 second is the time limit for this deceleration with some minor injury expected; therefore, the 25G value for 0.10 second is recommended. Reference 30 presents a detailed discussion of energy-absorbing restraint systems in the vertical direction.

A complete discussion of all factors pertaining to human tolerance to impact decelerations is outside the scope of this report; however, Reference 8 provides a summary of impact deceleration literature, and References 9 and 18 provide more detailed information on the limits of the human body. On the basis of all facts considered, it appears reasonable and practical to design personnel restraint harnesses up to the human tolerance limits indicated in Figure 2, because any weaker restraint harness could fail and expose personnel to unnecessary injury or death.

Airframe Limits

The limits being referred to here are those which the aircraft structure can withstand and still maintain a protective "shell" around the occupants; that is, the magnitude and duration of decelerations that the fuselage structure can withstand during an impact and still provide living space within the structure for the occupants. These limits are governed by several factors, such as impact velocity,

angle between flight path and terrain, strength of the basic aircraft shell, terrain composition, and others.

Table 1 is a summary of acceleration measurements made in various locations of different aircraft types in 20 crash-test experiments conducted by NACA and AvCIR. In all of these crash tests, a major portion of the protective shell was intact, and the accelerations experienced in these tests are, in general, less than the demonstrated personnel limits of Figures 1 and 2; therefore, it seems reasonable to use the personnel limits as a basis for restraint harness design criteria as discussed in the balance of this report.

Although the helicopter crashes (items 16-20) indicated vertical (headward) decelerations greater than man's tolerable limits, note that these values were measured on the floors of the aircraft and are attenuated somewhat by structure between the floor and the occupants. The floor decelerations measured can be further attenuated by the use of energy-absorbing systems as noted previously.[30]

RESTRAINT HARNESS EVALUATION

In order to obtain maximum protection against decelerative forces, an optimum harness would be one in which load is distributed uniformly over the entire body. This ideal situation is approached by an astronaut's restraint system, in which the harness is integral with a molded couch which distributes load over nearly all of the body's surface, but it is not considered to be very practical for U. S. Army aircraft. Figure 3 illustrates the value of increasing the area of body contact with the restraint system.

Other harnesses which are more practical than the astronaut-type restraint system have been developed over the years for forward-facing seats. The lap belt was used as early as World War I to prevent personnel from falling out of aircraft. A shoulder harness was added eventually to prevent the upper torso from swinging forward, "jackknifing"* about the lap belt fulcrum, and contacting environmental structure.

* "Jackknifing" denotes the coming together of the upper torso and legs during spineward decelerations.

TABLE 1

SUMMARY OF FULL SCALE CRASH TEST - FLOOR ACCELERATION DATA

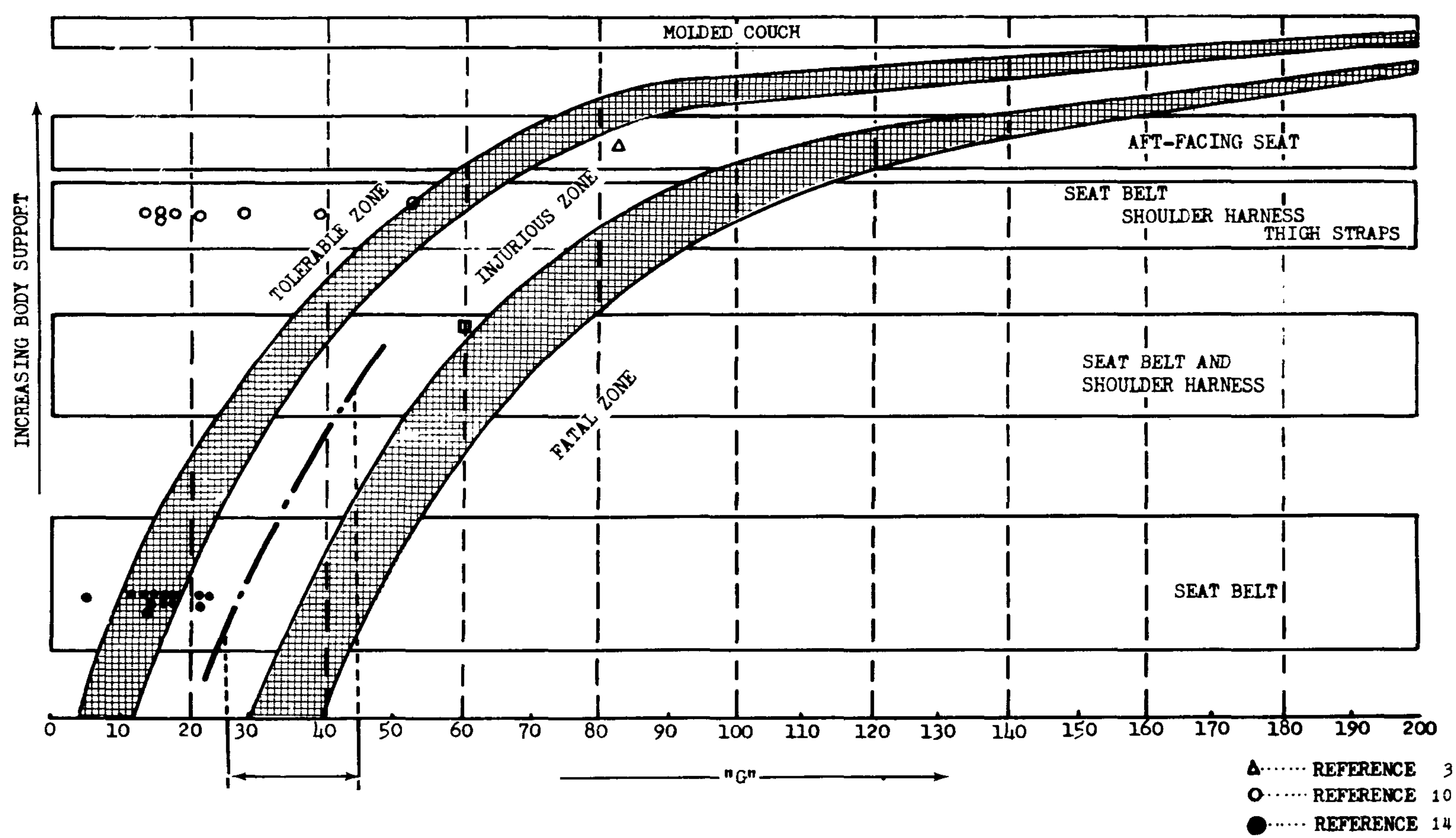
Line Item No.	Type Aircraft	Impact Angle (degrees)	Aircraft Attitude (degrees)	Impact Velocity (m.p.h.)	Location (in. from nose)	ACCELERATIONS LONGITUDINAL Peak Mag. (G)	Time of Occur. (sec.)	Pulse Dur.*	VERTICAL Peak Mag. (G)	Time of Occur. (sec.)	Pulse Dur.*	References
1	Piper J-3	55	55	42	Under Rear Seat	26.5	0.040	0.23	9	0.06	0.02	7
2	Piper J-3	55	55	47	Under Rear Seat	32.5	0.039	0.18	13	0.08	0.04	7
3	Piper J-3	55	55	60	Under Rear Seat	33.5	0.121	0.23	--	--	--	7
4	Fighter Navy FH-1	18	18	112	Cockpit Floor	20	0.06	0.18	--	--	--	1
5	Fighter Navy FH-1	22	22	112	Cockpit Floor	30	0.065	0.18	30 55	0.06 0.285	0.10 0.05	1
6	Fighter Navy FH-1	27	27	112	Cockpit Floor	140	0.065	0.09	--	--	--	1
7	Fighter Navy FH-1	4 (Ground Loop)	4 (Ground Loop)	112	Cockpit Floor	8	2.33	0.10	--	--	--	1
8	Fighter Navy FH-1	Cart Wheel 30° roll	Cart Wheel 30° roll	112	Cockpit Floor	9	0.135	--	15	2.2	0.03	1
9	C-46	5	5	81	270	2.5	0.190	0.33	2.5	0.265	0.35	22
10	C-46	15	15	93	250	10	0.120	0.22	15	0.095	0.18	22
					360	11	0.122	0.22	10	0.075	0.18	
					485	7	0.125	0.22	10	0.150	0.18	

					Seat							
4	Fighter Navy FH-1	18	18	112	Cockpit Floor	20	0.06	0.18	--	--	--	1
5	Fighter Navy FH-1	22	22	112	Cockpit Floor	30	0.065	0.18	30 55	0.06 0.285	0.10 0.05	1
6	Fighter Navy FH-1	27	27	112	Cockpit Floor	140	0.065	0.09	--	--	--	1
7	Fighter Navy FH-1	4 (Ground Loop)	4 (Ground Loop)	112	Cockpit Floor	8	2.33	0.10	--	--	--	1
8	Fighter Navy FH-1	Cart Wheel 30° roll	Cart Wheel 30° roll	112	Cockpit Floor	9	0.135	--	15	2.2	0.03	1
9	C-46	5	5	81	270	2.5	0.190	0.33	2.5	0.265	0.35	22
10	C-46	15	15	93	250	10	0.120	0.22	15	0.095	0.18	22
					360	11	0.122	0.22	10	0.075	0.18	
					485	7	0.125	0.22	10	0.150	0.18	
					680	9	0.125	0.22	8	0.170	0.18	
11	C-46	29	29	97	185	20	0.145	0.23	25	0.175	0.21	22
					335	22	0.145	0.23	18	0.135	0.21	
					490	20	0.150	0.23	12.5	0.160	0.21	
					685	17	0.155	0.23	10	0.195	0.21	
12	Lodestar	12 (Ground Loop)	12 (Ground Loop)	87	243	3.5	0.265	0.12	9	0.275	0.09	22
					312	3.5	0.260	0.12	9	0.275	0.09	
				63	243	7	1.653	0.13	40	1.653	0.13	
					312	7	1.680	0.13	28	1.680	0.13	
13	Lodestar	16	16	109	243	15	0.195	0.25	18	0.180	0.22	22
					312	13	0.185	0.25	16	0.215	0.22	
14	C-82	4	4	95	Long. 138 Vert. 140	6	0.150	0.17	12	0.30	0.17	22
15	C-82	16	16	91	Long. 340 Vert. 541	15	0.07	0.10	10	0.30	0.07	22
16	H-25 **	45	0	42	60	45	0.11	0.07	115	0.105	0.03	29
					105	36	0.09	0.07	61	0.095	0.06	

10	C-46	15	15	95	[illegible]	10	[illegible]	[illegible]	15	[illegible]	[illegible]	22
					360	11	0.122	0.22	10	0.075	0.18	
					485	7	0.125	0.22	10	0.150	0.18	
					680	9	0.125	0.22	8	0.170	0.18	
11	C-46	29	29	97	185	20	0.145	0.23	25	0.175	0.21	22
					335	22	0.145	0.23	18	0.135	0.21	
					490	20	0.150	0.23	12.5	0.160	0.21	
					685	17	0.155	0.23	10	0.195	0.21	
12	Lodestar	12 (Ground Loop)	12 (Ground Loop)	87	243	3.5	0.265	0.12	9	0.275	0.09	22
					312	3.5	0.260	0.12	9	0.275	0.09	
				63	243	7	1.653	0.13	40	1.653	0.13	
					312	7	1.680	0.13	28	1.680	0.13	
13	Lodestar	16	16	109	243	15	0.195	0.25	18	0.180	0.22	22
					312	13	0.185	0.25	16	0.215	0.22	
14	C-82	4	4	95	Long. 138 Vert. 140	6	0.150	0.17	12	0.30	0.17	22
15	C-82	16	16	91	Long. 340 Vert. 541	15	0.07	0.10	10	0.30	0.07	22
16	H-25 **	45	0	42	60	45	0.11	0.07	115	0.105	0.03	29
					105	36	0.09	0.07	61	0.095	0.06	
17	HUP-2 **	48	0	39	60	44	0.17	0.13	234	0.13	0.03	31
					105	35	0.12	0.13	125	0.12	0.045	
18	HUP-2 **	56	0	35	60	40	0.14	0.13	200	0.12	0.03	32
					105	20	0.13	0.13	188	0.115	0.06	
19	H-13	50	0	38	40	150	0.065	0.03	273	0.06	0.03	33
20	H-13	49	0	38	40	175	0.035	0.02	230	0.03	—	34

* The acceleration records obtained at floor level in the crash tests of line items No. 16 through 20 were generally composed of a series of successive individual pulses. The durations given in this table represent the total interval during which the primary decelerations occurred.

** The fuselage geometry of these aircraft are identical. The H-25 is an Air Force designation, and the HUP-2 is a Navy designation.



(The shaded areas indicate transition between the tolerable, injurious and fatal deceleration limits.)

Figure 3. Hypothetical Correlation of Restraint Systems and Human Tolerance to Short Duration Transverse Deceleration for Durations of the Order of 0.10 Second.

GENERAL RESTRAINT HARNESS REQUIREMENTS

Numerous methods of restraining the human body have been tried or can be proposed, but any practical harness which will be used routinely for short or long flights should be designed with consideration given to the following factors:

1. The harness should be light in weight and comfortable.

2. The harness should be easy and quick to don and remove.

3. The harness should preferably contain only one point of release, since a stunned or injured person might have difficulty in releasing more than one buckle.

4. The harness should provide freedom of movement to operate the controls of the aircraft. This requirement necessitates the use of an inertia-reel shoulder harness for pilots in most aircraft.

5. The harness should provide restraint in the vertical and transverse directions equal to the known tolerable limits shown in Figures 1 and 2.

6. The harness webbing should cover the maximum area in the shoulder and pelvic regions consistent with the other items listed.

LOWER TORSO RESTRAINT

The lower torso harness should provide adequate support to the pelvic region. It should limit vertical, transverse, and rotational movement of the pelvis. Adequate support of the lower torso can be accomplished very well if the occupant is fitted into a corset of strong webbing which is attached externally to the sides of the seat, but this type of harness is not considered to be very practical for Army personnel because too much time is required to don and remove it. The traditional lap belt combined with some kind of tiedown strap between the legs appears to offer adequate and practical restraint for Army personnel. The lap belt, tiedown straps, and associated problems are discussed in the following items.

Lap Belt Restraint Only

A thorough discussion of lap belt restraint is presented in References 2, 6, 15, and 20 and is not repeated in detail here; suffice it to say that lap belt restraint alone appears limited to approximately 25G for forward-facing personnel.[20] This limit is based primarily on the limits of internal body organs.

Maximum tolerance to deceleration is associated with maximum distribution of load as indicated in Figure 3. Maximum load distribution dictates maximum width of belt webbing, but other factors must also be considered. An optimum width belt is approached by considering these factors:

1. Comfort.

2. Webbing pressure during deceleration.

3. Belt webbing must not extend above iliac crests of pelvis.

If the belt is to be worn continuously, it must be comfortable, and comfort is governed by belt width as well as by weight and location of adjustment and release buckles. Operational experience indicates that two and three-inch-wide belts are not uncomfortable, but it seems probable that a four-inch-wide belt would be very uncomfortable, especially for low percentile personnel.

Obviously, the webbing pressure should be kept to a minimum, but it must be consistent with the third requirement. The webbing of a very wide belt (3 inches or greater) will pass above the iliac crests and thus increase the tendency of the belt to move upward into soft abdominal tissue because of the shoulder strap pull. As belt width is increased, it is also more likely to fold over (crease) between the thigh and pelvis, especially when thin webbing is used.

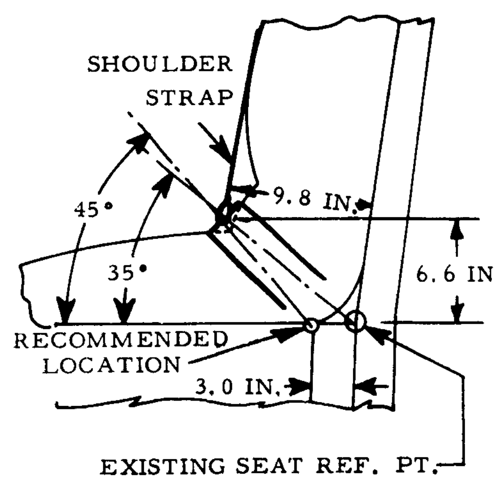
Thus, it appears that the upper limit of belt width is determined by comfort and the anatomical make-up of the pelvis, rather than by minimum webbing pressure. For example, the theoretical decrease in webbing pressure with increased belt width reaches a point of diminishing return beyond a width of 3 inches because belt pressure is not uniformly distributed in the pelvic region. In determining maximum belt pressure, reference is made to current FAA airline passenger seat belts, which apply 75 p.s.i. at the breaking strength of 3,000 pounds (3,000 $\div$ 2-inch width x 20-inch wrap). If this pressure is selected as a maximum, then

the 6,000-pound lap belt, recommended for use in Army aircraft, would require a 4-inch width; however, as noted previously, this width is impractical for several reasons.

On the basis of the foregoing discussion, it is recommended that a minimum width of 2.5 inches be considered for all lap belts. It should be understood that the existing 3.0-inch belts in current use are acceptable, but it appears that this belt does not offer enough additional protection over a 2.5-inch belt to justify its continued use, especially in view of its excessive 2.7-pound weight, which can be reduced to a maximum of 2 pounds with a reduction in width to 2.5 inches and a redesign of the metal fittings. A belt of greater width will possibly offer more protection to large personnel, but it is uncomfortable and can impinge on soft abdominal tissue of small personnel; therefore, the 2.5-inch belt is considered optimum from a standpoint of comfort, load distribution, and torso anatomy.

The belt centerline should pass through the crease of the hips at an angle of 45-55 degrees measured in respect to the seat pan. This angle will minimize the "submarining" of the torso under the belt which is caused by the shoulder strap pull upward. If the angle is less than 45 degrees, the tendency to "submarine" is increased; if the angle is greater than 55 degrees, the belt load is higher, which results in higher webbing pressure.

Current military crew-seat specifications state that the belt centerline should coincide with the seat back and cushion intersection. This location results in a 35-degree angle with the seat pan as illustrated by the sketch at right.



Note: Hip height and pelvic depth taken from Reference 12 for 50 percentile man.

Forward displacement during deceleration, resulting from belt elongation, will further reduce this angle; therefore, it is recommended that the attachment

location be changed as shown to maintain a minimum angle of 45 degrees.

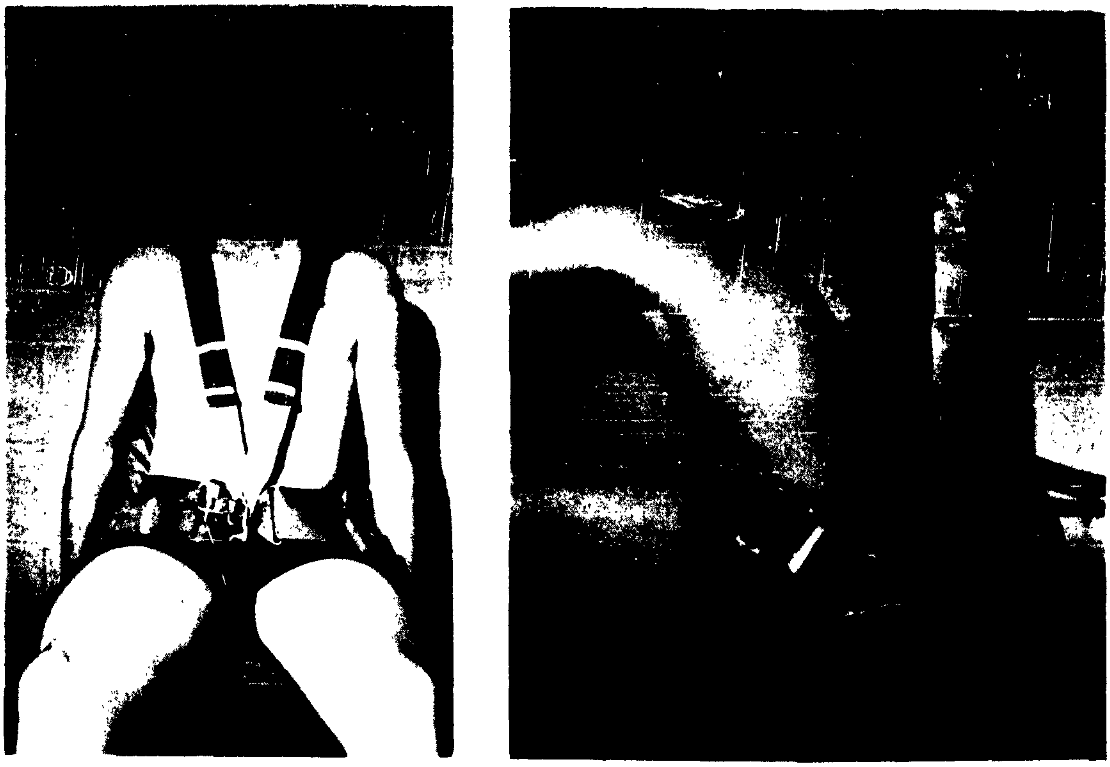
Pelvis Rotation

When the body is subjected to a large spineward deceleration, the inertia load of the legs and hips tends to rotate the pelvis about the lap belt fulcrum point and pulls or "submarines" the body under the belt. To illustrate this "submarining", a series of photographs were made of a male subject in an H-21 crew seat.* A standard 3-inch lap belt and 1.7-inch shoulder harness were worn to depict the restraint harness in military aircraft. The lap belt and shoulder harness were loosened to allow a 1-inch elongation on both ends of the belt and a 4-inch elongation of the shoulder harness to simulate the webbing stretch under dynamic loading. The harness elongation was unchanged for the photographs of Figures 4 through 6. The dynamic load was simulated by two men pulling forward on the arms and legs in these photographs.

No Load Condition — Simulated Spineward Deceleration

Figure 4. Standard Military Harness.
Note extreme position of buttocks at forward edge of seat cushion and the lap belt buckle position.

* The side braces of this crew seat were removed to facilitate the photography.



No Load Condition Simulated Spineward Deceleration

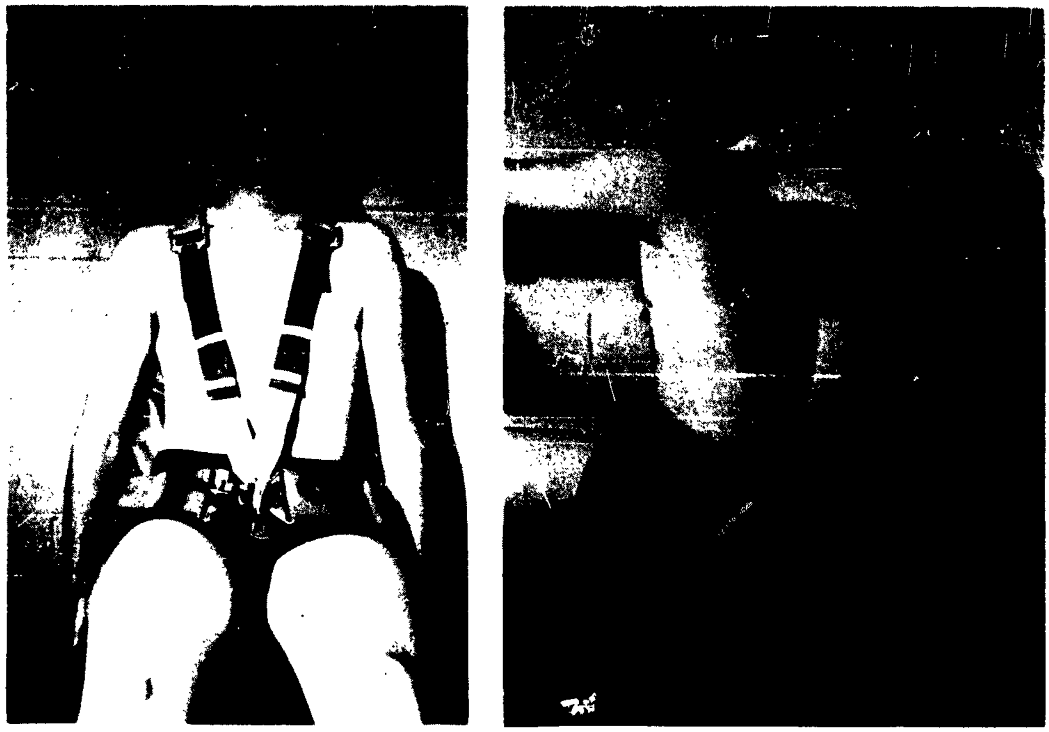
Figure 5. Standard Military Harness With Inverted "V" Straps. Note that buttocks do not move forward on seat cushion.

In Figure 4, the body is subjected to a simulated deceleration in which the torso is "submarined" under the belt. The "submarining" is aided by the upward pull of the shoulder harness straps. Note the position of the lap belt buckle in the solar plexus area; this condition can cause serious injuries. An actual crash loading of this nature would place a severe, bending load on the spinal column. If a headward deceleration occurs simultaneously with the spineward deceleration, the spinal column is loaded in compression and bending with a wedge type vertebral fracture a probable result. The mechanism of pelvic rotation and vertebral fracture is discussed more fully on pages 10, 11, 34, and 35 of Reference 21.

Inverted "V" Straps

Significant pelvic rotation can be prevented by addition of a restraining force below the lap belt. One method of applying this restraint is shown in Figure 5. A mockup of 1. 7-inch-wide inverted "V" straps

attached to the standard 3-inch lap belt is shown. These straps pass under the buttocks along the top of the seat cushion to attachment points in the seat bucket. The inverted "V" straps did not seem to be uncomfortable in this mockup evaluation, but further operational use is necessary to prove that they are not uncomfortable for long flights.



No Load Condition — Simulated Spineward Deceleration

Figure 6. Standard Military Harness With Lap Belt Tiedown Strap. Note that buttocks do not move forward over edge of seat cushion as in Figure 4.

Note the position of the torso in Figure 5 when subjected to the same simulated loads which were applied in Figure 4; the use of the inverted "V" straps was the only difference in the two photographs. Pelvis rotation is arrested by the strap pressure on the forward and lower portion of the buttocks. Undue concern over the pressure of the straps on the genital organs should be alleviated by the following quote from Reference 2. "A majority of the 53 experiments reported in this series were accomplished

with variations of this basic design*, and all twelve subjects had complete confidence in it (inverted "V" straps) after experience proved that the genitalia could not be impinged on in any way by the straps during deceleration."

During the experiments of Reference 2, volunteers refused to be subjected to decelerations higher than 17G's with a standard 3-inch lap belt and 1.7-inch shoulder harness combination; however, after adding 3-inch, inverted "V" straps and a 3-inch shoulder harness, volunteers withstood up to 45G without injury as indicated in Figure 2. Strain gage recordings indicated that the inverted "V" straps carried as much as 35 percent of the decelerative loading, a significant value.

Although the volunteers in the above experiments used 3-inch wide inverted "V" straps to sustain deceleration above 30Gs, the initial experimentation was accomplished with 1.7-inch straps. The width of strap was increased to reduce pressure on the buttocks and thereby to make the 30G+ decelerations more tolerable to the volunteers.

The 3-inch-wide inverted "V" straps which were looped over the top of the seat belt for the above experiments do not appear to be practical for operational use in aircraft for several reasons:

1. The 3-inch width appears to be too wide for comfort because of the constant rubbing against the thighs.

2. No adjustment provision was provided on the experimental harness, but an adjustment buckle is necessary to allow for torso variations.

In view of the above, further evaluation of an operational type inverted "V" harness for comfort and effectiveness should be conducted.

Lap Belt Tiedown (Single Strap Type)

The upward movement of the lap belt caused by shoulder harness pull can be reduced considerably by attachment of a single strap to the forward edge of the seat pan.

* The "basic design" refers to the military lap belt and shoulder harness with the inverted "V" straps added.

This arrangement is illustrated in Figure 6, and the effectiveness of the lap belt tiedown strap can be seen. Note that the belt buckle does not dig into the lower ribs as is evident in Figure 4. Note also that the tiedown strap holds the belt in its proper position in front of the pelvis rather than above the pelvis as in Figure 4.

The single strap is not intended to restrain the pelvis; it is intended to enable the lap belt to restrain the pelvis more effectively.

UPPER TORSO RESTRAINT

The upper torso portion of a restraint harness would, ideally, give complete support from the waist to the neck. Such a harness has been evaluated by the Navy[24] and was found to be effective in distributing pressure over the entire chest; however, as noted earlier under lower torso restraint, a corset-type harness is not recommended because egress would be slower than from a standard belt and shoulder strap combination with a single release point.

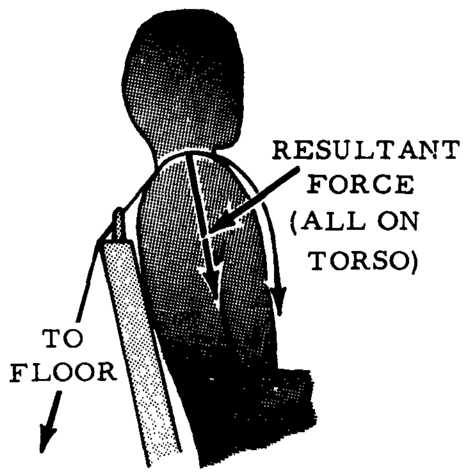
Evaluation of Harness Types

Various types of harnesses can be devised to restrain the upper torso; however, if the harness is to be released at a common point with the lap belt, the choice is narrowed. The basic, double-shoulder straps illustrated in Harnesses A through F are the only known harness types possessing the single-point-release feature. These harness types have been used by the Armed Forces since World War II, and are considered to be adequate, with the reservation that they be used with some form of tiedown to prevent upward movement of the lap belt. A harness which would provide more lateral restraint is desirable, but it appears that any such harness would require more than one point of release. The diagonal shoulder straps shown in Harness C do provide more lateral restraint, but this harness requires further evaluation before it is recommended.

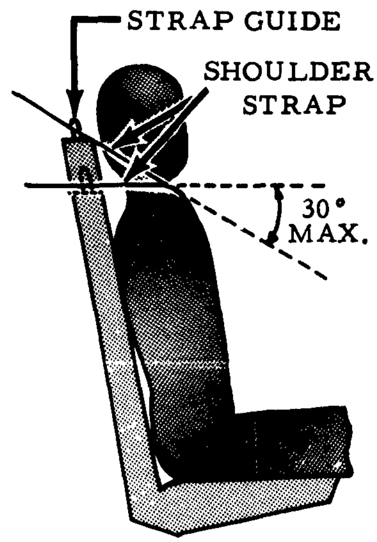
As already noted in Figure 3, maximum tolerance to deceleration is associated with maximum load distribution; therefore, it would seem logical to utilize a maximum shoulder strap width consistent with comfort and weight. In order to reach the voluntary limits noted in Figure 2, 3-inch webbing was used, and it appears to be

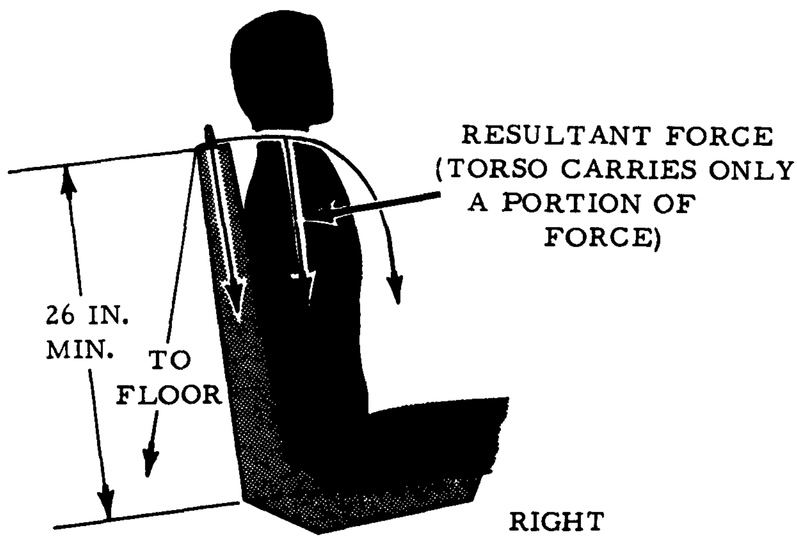
practical to increase the width of future shoulder harnesses to a minimum 2.0 inches as a practical compromise between webbing pressure and harness weight. An increase in harness width from the present 1.7 inches is aimed primarily at reducing the physiological effects of deceleration in the hope that a rapid egress can be made from crashed aircraft.

Shoulder straps should pass over the shoulders in a horizontal plane, or at any upward angle not to exceed 30 degrees, as illustrated by the sketch below on the right side.



WRONG





RIGHT

Any installation which places the straps at an angle below the horizontal adds additional downward force on the seat occupant's spine as shown in the sketch on the preceding page on the left side. A minimum seat back height of 26 inches is recommended for those installations in which the shoulder straps pass downward over the seat back , as illustrated by the lower sketch on the previous page. This seat back height will insure that the straps are perpendicular to the spine of a 98 percentile man.

Inertia Reel Considerations

An inertia reel must be used with a shoulder harness to allow the pilot freedom to reach all controls. The operation of the inertia reel is not discussed since it is covered by manufacturing brochures and by Reference 19; however, one point in regard to the reel's operation should be considered. The automatic inertia-locking mechanism of the reel is presently set to actuate between 2 and 3G decelerations in accordance with MIL-R-8236.

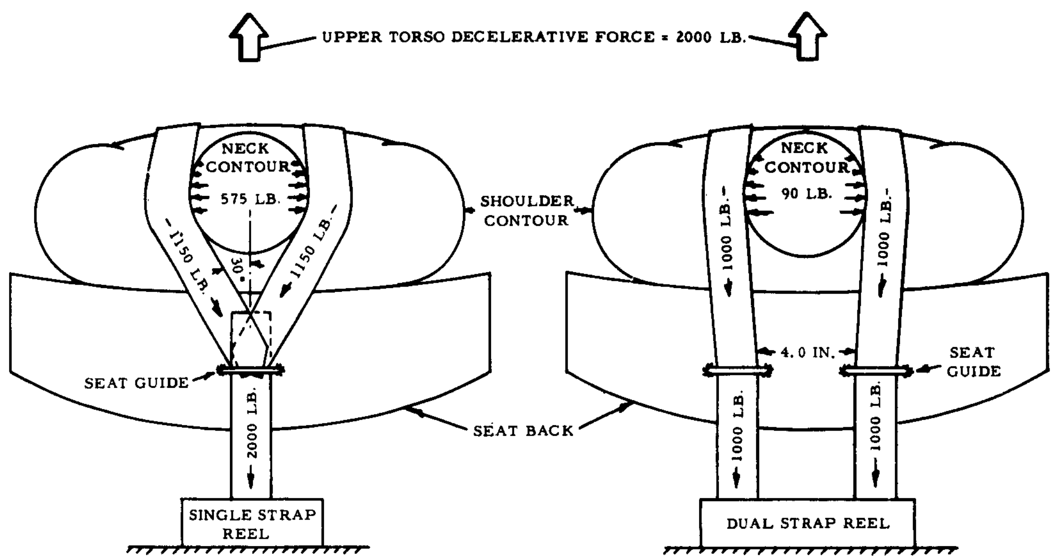
This setting apparently presents no operational problems for the impact-sensitive reels (types MA-1, MA-2, MA-3, and MA-4); however, the rate-of-extension reels (types MA-5 and MA-6) are apparently subject to being actuated inadvertantly. It is easy to visualize the locking of the reel during a critical aircraft maneuver which could produce dire results.

The minimum 2G value dictates that a shoulder movement of 64 feet per second per second is necessary for actuation which deceleration appears higher than the normal torso movements expected in the cockpit; nonetheless, the contractor has on file several complaints from pilots using this type reel which indicate that the reel can be actuated inadvertantly. In view of this, it seems logical to increase the setting to a minimum of 2.5G (80 fps^2) to a maximum of 3.5G (112 fps^2) to insure that the reel cannot be actuated inadvertantly. The upper limit of 3.5G is not considered excessive, although it is probably a maximum value above which a seat occupant should not be subjected without shoulder strap retention.

The existing single-strap inertia reel described by MIL-R-8236 is apparently very effective and easy to use. However, a dual-strap inertia reel would offer additional advantages which are worth considering. A comparison of the single-strap and dual-strap reels is made in Figure 7. Note the steep angle at the back of the pilot's neck on the single strap reel. This angle is

necessary if a narrow guide rail on the seat back is used, and the narrow guide is definitely beneficial in that it prevents excessive lateral movements.

The additional comfort offered by the wider spacing of the dual-strap reel is apparent. The dual-strap reel would also reduce the pivoting of the torso in a lateral direction during lateral decelerations.



NOTE: 1. THE 2000 LB. FORCE INDICATED IS THE APPROXIMATE SHOULDER HARNESS LOAD EXPERIENCED DURING A 30G DECELERATION BY A 200 LB. SEAT OCCUPANT.
2. NECK CONTOUR SHOWN REPRESENTS A 50 PERCENTILE MAN.

Figure 7. Comparison of Forces on the Neck for Dual Strap and Single Strap Shoulder Harness Inertia Reels.

A proposal for the manufacture of a dual-strap reel, in accordance with the strength requirements of MIL-R-8236, has been solicited from three companies with the following results:

	Weight Increase	Cost Increase
Proposal 1	0.8 pound	15 dollars*
Proposal 2	0.6 pound	Not quoted
Proposal 3	0.6 pound	Not quoted

* Based on order of 1,000 reels.

The dual-strap reel appears to be worthy of further development and evaluation.

RESTRAINT FOR SIDE-FACING PERSONNEL

Spineward forces on forward-facing personnel become lateral right or left for side-facing personnel. The side-facing restraint harness should provide protection equivalent to that of the forward-facing harness, and it should also contain only one release point. An ideal harness would apply decelerative force uniformly over the seated torso profile, but this type of restraint combined with a single release point appears to be an unattainable design at present. One or more chest bands combined with shoulder straps would offer adequate upper torso restraint, but an additional release buckle would be required. As a result, the standard lap belt combined with some form of upper torso restraint is probably the best compromise for a single-point-release harness.

Experimental tests conducted by the Navy[11] indicated that a single, diagonal shoulder strap with a shoulder band attached was adequate for transverse deceleration, but it did not prevent the subsequent rebound out of the harness. This harness is illustrated in Figure 8.

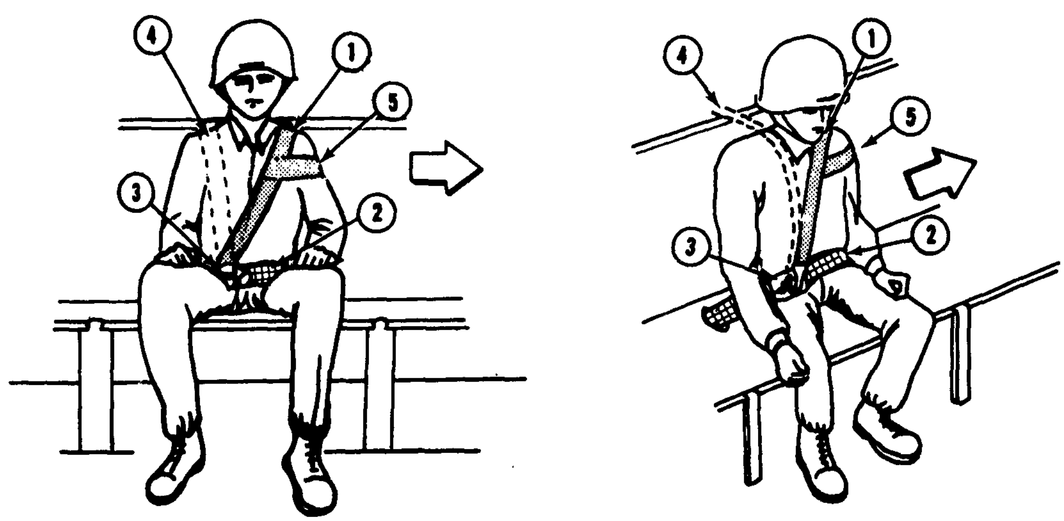


Figure 8. Restraint Harness for Side-Facing Personnel. Consists of (1) Diagonal shoulder strap, (2) Lap belt, (3) Release buckle, (4) Rebound shoulder strap, and (5) Arm band.

The diagonal shoulder strap, which is placed on the forward side of the neck, offers much more restraint to expected impact loads than the standard, two-strap harness used by forward-facing personnel. It also requires only one point of release with the lap belt. If an additional shoulder strap, as noted by the dashed lines, is added to alleviate the rebound problem, this harness appears to be worthy of further development.

The experimental tests of Reference 11 also indicated that the legs are straightened, as the body pivots in the direction of decelerative force, and are brought into contact with the seat back; however, if side-facing personnel are seated on a 20-inch spacing, it can be surmised that the leg movement is reduced considerably by the adjacent seat occupant. The occurrence of simultaneous headward deceleration will also reduce the tendency of the legs to rotate, as verified by full-scale helicopter crash tests, which indicate that side-facing anthropomorphic dummy legs do not pivot up to the seat level. Statistical data also indicate that a great majority of fixed-wing aircraft accidents contain a headward deceleration at initial impact which would reduce the pivoting of the legs for side-facing personnel. In view of the Army's convertible aircraft designs which require conversion from a troop carrier to cargo carrier in a matter of minutes, the additional complication of leg restraint for side-facing personnel is not believed to be practical.

Maximum benefit from shoulder straps, for side-facing personnel, is obtained when they are mounted level with or only slightly above shoulder level. Shoulder harnesses in some aircraft have been mounted above head level which minimizes their effectiveness; the angle of the shoulder strap should not exceed 30 degrees to the horizontal as noted earlier. The straps have also been attached to the same support tube utilized for the seat back support, and accidents have indicated that the failure of the seat back support made the shoulder harness worthless. Previous failures of inadequately attached shoulder straps should not be construed to mean that shoulder straps should be eliminated for side-facing personnel.

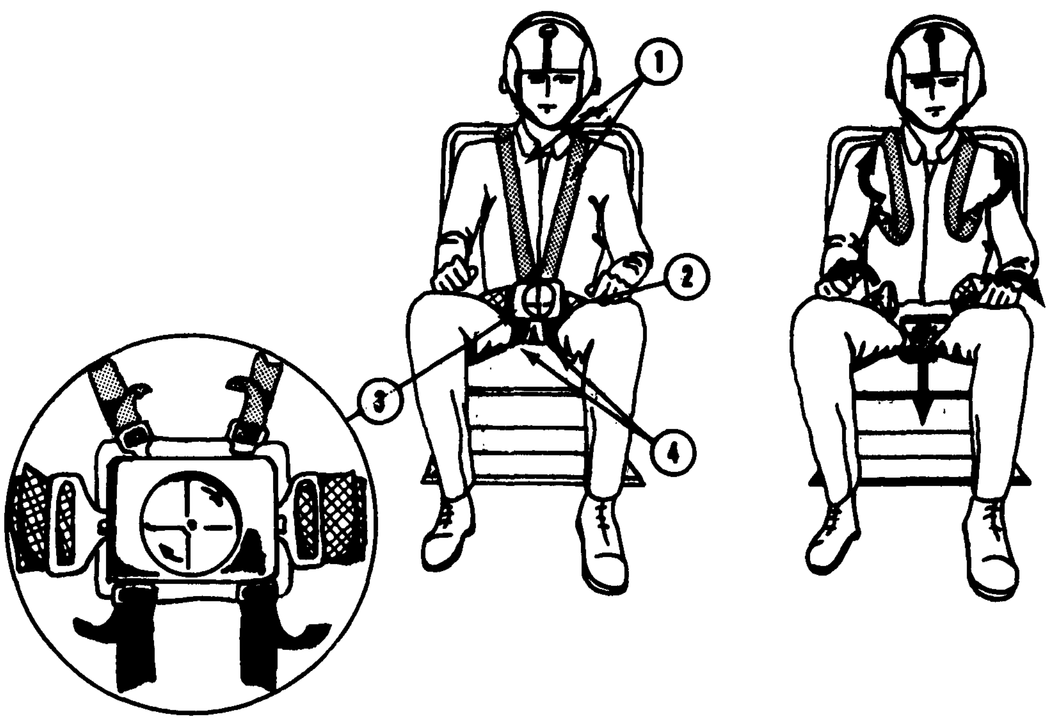
Lap belt and shoulder harness combinations are most effective when used with an adequate strength seat; the seat and restraint harness should be designed as an integral unit. When shoulder straps and belt are attached to the seat, seat failure renders the entire restraint harness worthless. When they are attached to basic structure instead, seat failure certainly reduces the effectiveness of the harness because the torso can "flail" in the loose harness and come into contact with solid structure; but the restraint provided is certainly better than none at all.

Existing side-facing troop seats in U. S. Army aircraft are under-strength and not designed to provide adequate restraint.[30] Until the present troop seats are replaced as recommended in Reference 30, the addition of shoulder straps is not considered to be practical or consistent with the remainder of the tiedown chain.

A restraint harness for side-facing troops should be developed simultaneously with a new troop seat which eliminates existing deficiencies. The standard, double-shoulder strap and lap belt combination is the preferred harness for side-facing troops until a better harness is developed and evaluated.

DISCUSSION AND ILLUSTRATION OF SEVERAL RESTRAINT HARNESS CONFIGURATIONS

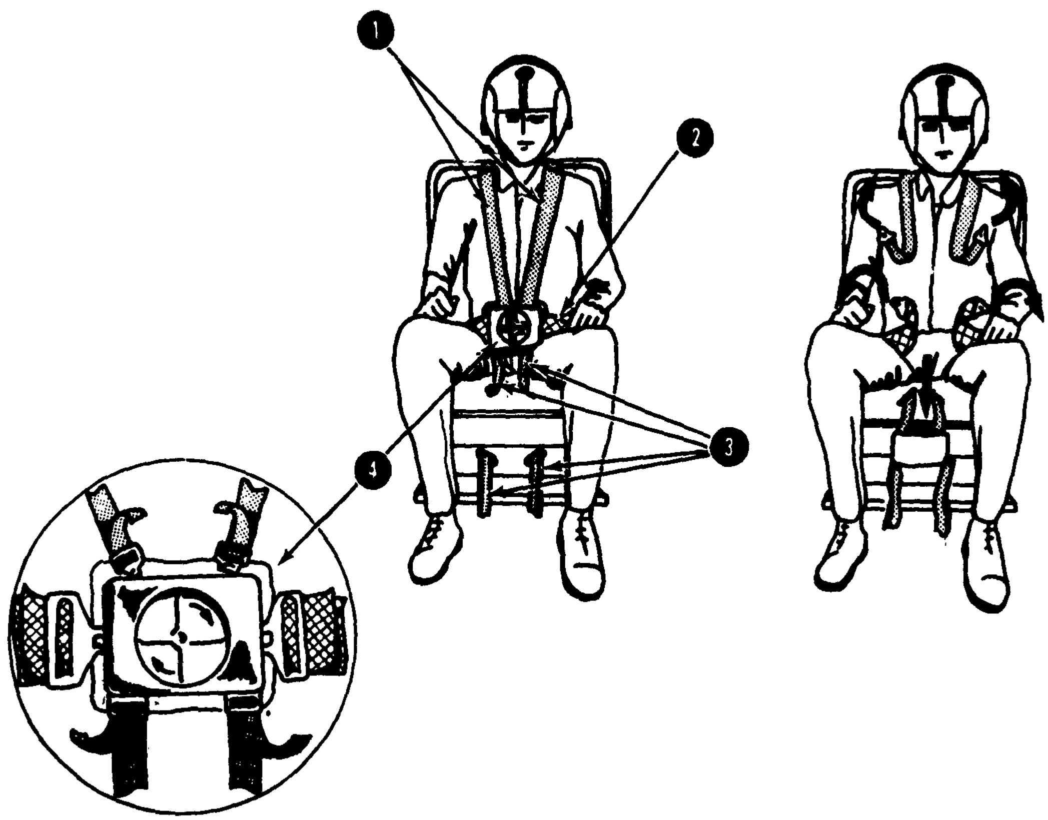
Several types of single-point-release harnesses are considered as shown in the following sketches.



Harness A - Consists of (1) "Snap-In" Shoulder Straps, (2) "Snap-In" Lap Belt, (3) Quick-Release Buckle, and (4) Inverted "V" Straps.

The Harness A concept has a single-point release buckle which is an integral part of the inverted "V" straps. The inverted "V" straps and release buckle drop between the legs upon release of the shoulder harness and lap belt. It appears that this harness can be donned more rapidly than the present military harness and the inverted "V" straps will provide added protection.

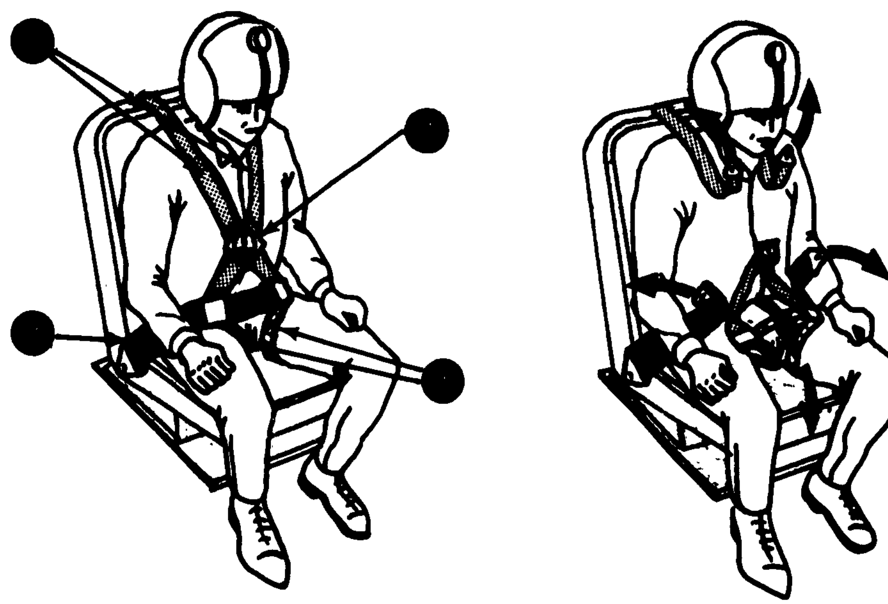
This harness should be capable of restraining personnel up to the known tolerable limits indicated in Figures 1 and 2; however, the release buckle and other fittings must be designed, and a prototype built and evaluated before it is considered for use in operational aircraft.



Harness B - Consists of (1) "Snap-In" Shoulder Straps, (2) "Snap-In" Lap Belt, (3) Thru-The-Seat Straps, and (4) Quick-Release Buckle.

The Harness B concept is identical to Harness A with the exception of the thru-the-seat straps. The thru-the-seat straps attach to the release buckle identical to Harness A, but the other ends attach either to the inside of the seat pan or to structure beneath the seat.

The thru-the-seat straps do not appear to be as effective in providing pelvic restraint as the inverted "V" straps depicted in Harnesses A and D because they cannot be adjusted for pelvis depth variations and they do not pass underneath the buttocks as do the inverted "V" straps. A mockup of this harness also indicated that it was not as comfortable to wear as Harnesses A and D; therefore, it is not recommended for further evaluation.

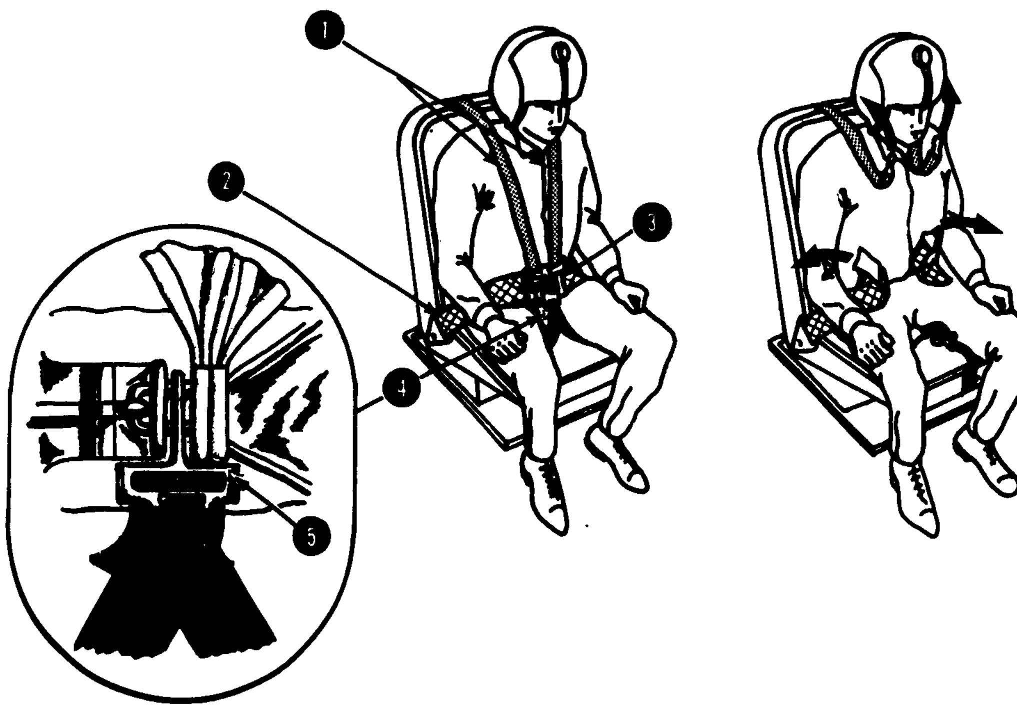


Harness C - Consists of (1) "Snap-In" Shoulder Straps, (2) "Snap-In" Lap Belt, (3) Quick-Release Buckle, and (4) Thigh Straps (Integral with Center Lap Belt).

This harness is unique to the other harnesses illustrated because the quick release buckle is located remote from the lap belt release point. Upon release, the harness breaks apart at three points: the diagonal shoulder straps break at the release buckle, and the lap belt breaks at both sides of the hips; the lower part of the shoulder straps, center portion of lap belt, and thigh straps drop between the legs. Flexible cables are required inside the webbing between the release buckle and the belt release points. This fact makes this harness more complex

to design and manufacture than the other harnesses discussed; however, the diagonal shoulder straps would definitely offer more lateral restraint than the vertical straps shown in the other harnesses. Although this harness has not been worn in mockup form, it appears to be as comfortable to wear as any of the others discussed.

This harness appears to offer restraint equal to or better than that of Harness A; therefore, it is recommended for further evaluation to determine its functional and operational suitability.



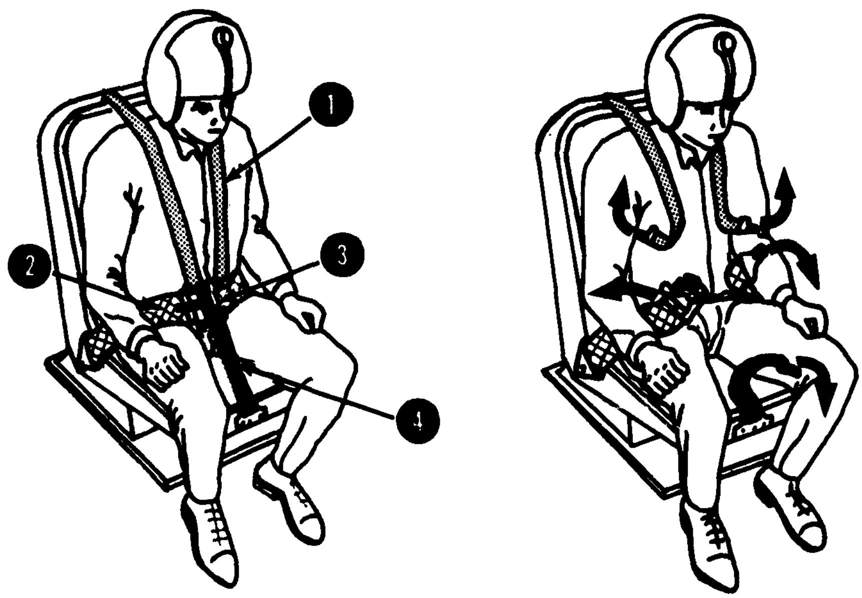
Harness D - Consists of (1) Standard Military Shoulder Straps, (2) Standard Military Lap Belt, (3) Standard Military Release Buckle, (4) Inverted "V" Straps, and (5) Loop and Adjustment Buckle Combination.

This harness is similar to Harness A, but the inverted "V" straps are not integral with the release buckle. The inverted "V" straps lie flat on top of the seat cushion and attach to the release buckle by the metal loop/adjustment buckle (5) as illustrated in the inset above. This type harness is recommended by Colonel John P. Stapp; the following quote is taken from his conclusions (Reference 2, page 34).

"The minimum modification of the existing USAF lap belt and shoulder harness for adequate protection up to 45G and 36 psi consists in adding the inverted-V leg strap and using No. 13 nylon in place of No. 8 nylon in the shoulder straps."

The 36 psi value indicated is based on the use of 3-inch-wide shoulder harness and thigh straps; however, as noted before, after a mockup evaluation of this harness, it is believed that a 1.7-inch inverted "V" strap is more comfortable. An adjustment buckle will be needed to fit the inverted "V" straps to varying torsos, and it appears preferable to locate it as shown in the inset to permit rapid adjustment.

The above harness is not recommended for immediate installation in existing Army aircraft; further evaluation of an operational type harness by decelerative sled runs to determine its comfort and effectiveness is recommended.



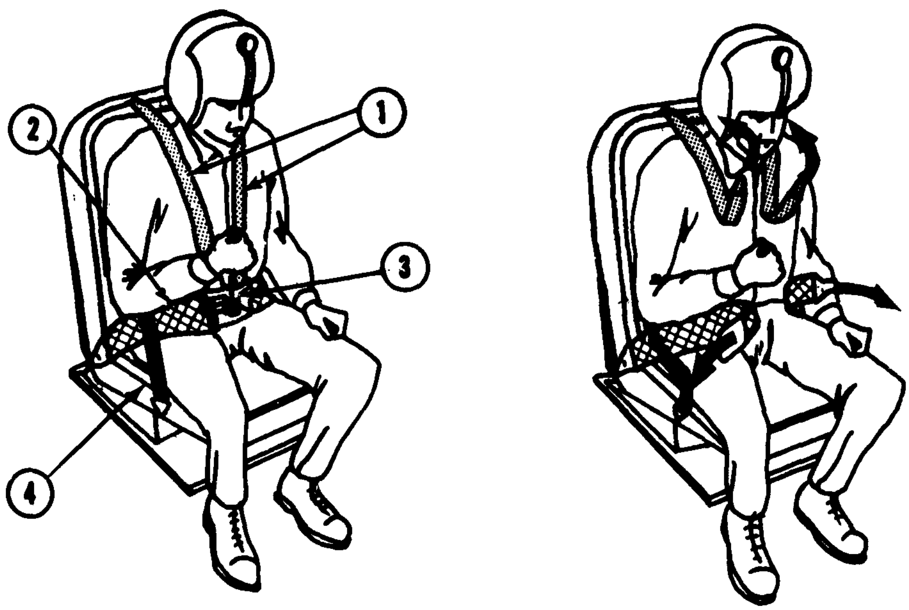
Harness E - Consists of (1) Standard Military Shoulder Straps, (2) Standard Military Lap Belt, (3) Standard Military Release Buckle, and (4) Lap Belt Tiedown Strap.

This harness utilizes a lap belt tiedown strap; this strap is considered to be very effective in resisting the upward pull of the shoulder straps. It should be comfortable to wear since it does not

contact the body, and fitting the metal loop over the release buckle is easy when donning the harness. The tiedown strap consists of standard parts available off-the-shelf, and it can be installed by military personnel in the field.

The belt tiedown strap is considered to be a very worthwhile addition to the standard military harness; this modified military harness is preferred for Army aircraft at the present time.

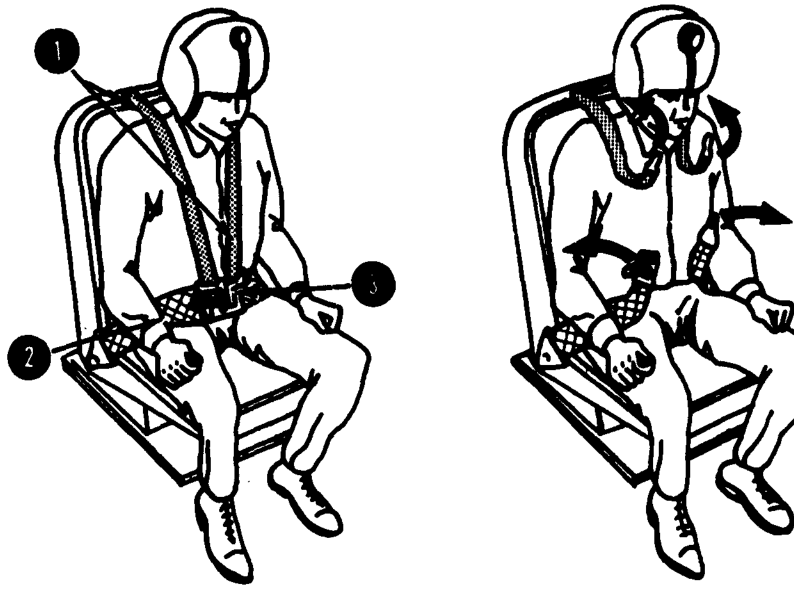
It is noteworthy that a tiedown strap is in use on nearly all commercial jet transports in service today, and it is being installed in RAF aircraft. Army personnel should readily accept the additional protection this strap provides.



Harness F - Consists of (1) Standard Military Shoulder Straps, (2) Standard Military Lap Belt, (3) Standard Military Release Buckle, and (4) Side Tiedown Straps.

This harness is not as effective as Harnesses A through E, but the side tiedown straps do offer resistance to the upward, shoulder strap pull on the lap belt. Although the belt buckle could still be pulled upward into the abdomen, the peripheral ends of the belt would be restricted against moving over the iliac crests of the pelvis. This installation is used on some models of the AO-1 ejection seat, and it is considered an excellent addition to the standard military lap belt.

The retrofit of the side straps would not be as simple as the installation of the Harness E tiedown strap since the lap belt would have to be removed in order to have the side strap sewn into it, but the side strap attachment to the seat bucket is very simple. This harness is recommended as a second alternate to Harness E.



Harness G - Consists of (1) Standard Military Shoulder Straps, (2) Standard Military Lap Belt, and (3) Standard Military Release Buckle.

This harness offers the same restraint provided by all the other harnesses, with the exception that it does not prevent the "ride up" of the belt due to the shoulder harness load nor does it prevent "submarining" of the torso under the lap belt. This harness is recommended only if it is modified to Harnesses E or F.

LOAD DISTRIBUTION ON RESTRAINT HARNESSES

The ratio of load carried by the components of a restraint harness cannot be precisely determined due to several varying parameters:

1. Torso weight distribution.

2. Coefficient of friction between buttocks and seat cushion.

3. Coefficient of friction between upper torso and shoulder harness. (This factor would affect the tiedown strap load.)

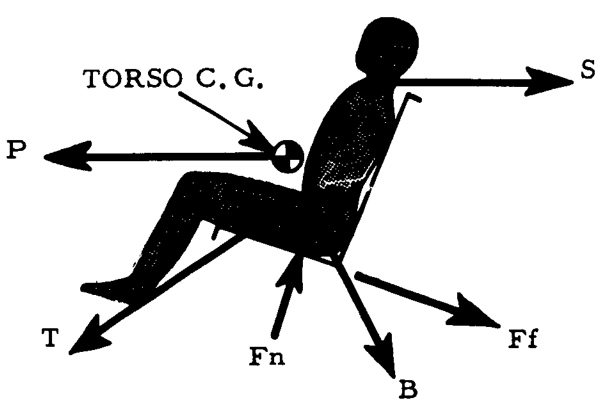
4. Adjustment of lap belt and shoulder harness (a loose harness causes higher loads).

5. Direction of decelerative force. (A downward, vertical force increases the normal load on the seat cushion, and hence reduces belt load.)

Theoretical Calculations

A theoretical analysis of load distribution, based on a torso C. G., as listed in MIL-S-5822, was conducted with and without a single tiedown strap, but a load distribution with the inverted "V" strap was not analyzed due to the indeterminate nature of loading. Parameter (1) was varied from a 2 percentile to a 98 percentile man as noted in Reference 12; parameters (2) and (3) (friction coefficient) were varied from 0.25 to 0.75. It was assumed that the lap belt and shoulder harness were adjusted equally.

The load distribution as a percentage of the total decelerative force (P) varied as indicated by the following sketch.



Force Symbols

P = Total Decelerative Load

S = Total Shoulder Harness Load

B = Total Lap Belt Load

F_f = Seat Friction Load

F_n = Seat Normal Load

T = Single Tiedown Strap Load

With Tiedown Strap	Without Tiedown Strap
S = 33-58%	S = 25-38%
B = 30-64%	B = 43-83%
T = 16-29%*	

* The tiedown strap load is calculated as a pure tension load applied by the shoulder straps; it is not intended to be loaded by the torso.

Note the marked increase in shoulder harness load when the tie-down strap is used. This marked increase is due to the following:

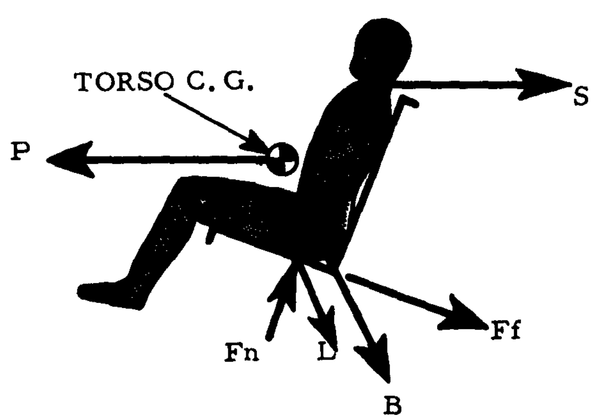
1. The lap belt does not move upward when a tiedown strap is used; therefore, the shoulder harness receives a higher ratio of the total load.

2. The addition of the tiedown strap force changes the equilibrium of the force diagram.

Experimental tests (References 7, 17, and 23) with anthropometric and anthropomorphic dummies indicated shoulder harness (S) loads equal to one-half the lap belt (B) loads; these values agree closely with the theoretical values calculated without a belt tiedown strap.

Experimental Data

Data gathered from Reference 2 indicates a load distribution on a shoulder harness, lap belt, and inverted "V" strap as a percentage of the combined harness loads, i.e., a percentage of (S + B + L). This percentage yields the ratio between the harness components, which is all that is needed.



$S = 22\% - 41\%$

$B = 33\% - 62\%$

$L = 16\% - 30\%$

Force Symbols

P = Total Decelerative Load

S = Total Shoulder Harness Load

F_f = Seat Friction Load (not measured)

B = Total Lap Belt Load

F_n = Seat Normal Load (not measured)

L = Total Strap Load (inverted "V")

The volunteer personnel utilized for the above experiments varied in height from 66.5 to 72 inches and in weight from 150 to 206 pounds. These personnel would vary approximately from a 20 percentile to a 90 percentile man in accordance with Reference 12.

Note that the previous theoretical calculations, for the tiedown strap harness, agree with the experimental data fairly well. The greater variation of the theoretical values is probably due to the greater variation of the input parameters.

In view of the wide variation in the theoretical load distribution discussed previously, the upper limits of these values are not recommended for design loads, at least not until further experimental tests verify the extreme values. Instead, the upper limits of the experimental data listed above are recommended, with a 10 percent safety factor added to cover variation of parameters which were not explored. Thus, the experimental values are multiplied by 1.10.

If a 45G load is accepted as minimum restraint, in the transverse direction as noted in Figure 2, the harness components should be designed as follows:

Shoulder Harness = .41 x 1.10 x 9000 = 4050 lb say 4000 lb

Lap Belt = .62* x 1.10 x 9000 = 6140 lb say 6000 lb

Inverted "V" Strap = .30 x 1.10 x 9000 = 2970 lb say 3000 lb

Belt Tiedown Strap** = 2530 lb say 2500 lb

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* Note that this value is based on the use of "V" straps and that it could be higher if no straps were used as noted by the previous theoretical calculations, but it is assumed that either the single tiedown strap or the inverted "V" straps will be used.

** This is a theoretical value based on a 4000-pound shoulder strap load, an 0.33 friction coefficient, and 80 degrees wrap angle between shoulder and strap.

Existing Lap Belt Strength

Existing U. S. Army military lap belts meet the strength requirements stated in five different military specifications as listed in Table 2. These specifications indicate a minimum 2500-pound end-to-end strength (5000-pound loop strength) with the exception of MIL-B-6703, which specifies a 4500-pound loop strength. It has been demonstrated in References 7 and 23 that the dynamic strength of some lap belts is as much as 50 percent greater than their static strength for very short periods (.01 second) of time. In view of this, no change is recommended for the standard, 3-inch-wide, 5000-pound lap belt since it will probably sustain loads in excess of the recommended 6000 pounds for very short time spans. It is recommended that all of the 1.72-inch-wide belts (MIL-B-6703, MIL-B-8242, and MIL-B-8437) not be used on new designs because of the very narrow width. It is further recommended that MIL-B-5032A belts not be used on new designs since the 9000-pound loop strength is in excess of known requirements.

It is also recommended that dynamic evaluation tests be conducted on lap belts to develop a minimum-weight belt to withstand 6000 pounds for .10 second; preliminary calculations indicate that such a belt could be designed to weigh one-half to one pound less than the present 2.7-pound belt.

It is recommended that one military specification be written to cover procurement of seat belts for all Army aircraft. It appears that one universal seat belt for all harness designs is adequate and acceptable.

Existing Shoulder Harness Strength

Existing U. S. Army shoulder harnesses meet the strength requirements stated in five military specifications as listed in Table 3. Note that these specifications call out four different strengths: 1800 lb, 3600 lb, 3775 lb, and 4000 lb. It is noteworthy that the 3600-pound harness actually weighs 0.07 pound less than the 1800-pound harness; this is due to the fact that the metal fittings on both harnesses are identical, and the 1800-pound harness has an extra adjustment buckle which more than offsets the decrease in webbing weight.

TABLE 2

MILITARY SPECIFICATIONS FOR LAP BELTS - U. S. ARMY AIRCRAFT

Military Spec.	Date	Type	Width (in.)	Examples of A/C Used On	Applicable Drawings	Ultimate Strength (lb)	
MIL-B-6703*	5-13-50	--	1.72	HU-1A	AN6506	4500	Loop
None	1954	MD-1	3.0	H-34 & H-21	54H19650(AF)	2500	Single Pull
None	1954	MD-2	3.0	H-21 & AC-1	54H19651(AF)	2500	
MIL-B-5032A (Navy)	8-13-56	Pilot	3.0	U-1A	MS22033	9000	Loop
MIL-B-8242	--	C-3A (troop)	1.72	H-19	AF56E589	2500	Single Pull
MIL-B-8437A (USAF)	3-29-57	MC-1A (troop)	1.72	--	56E590	2500	
MIL-B-8607A (Navy)	--	Pass./troop	1.94	HU-1B	49A6557 (end fittings)	5000	Loop

* This specification is used to state strength requirements for the HU-1A troop lap belt No. 204-070-759 which is a 2-inch-wide airline-type belt.

TABLE 3
MILITARY SPECIFICATIONS FOR SHOULDER HARNESSES - U. S. ARMY AIRCRAFT

Military Spec.	Date	Type	Width (in.)	A/C Used On	Applicable Drawings	Ultimate Strength (lb)
MIL-H-3697*	5-6-52	B-15	--	H-21	44G5443	--
		G-3	--	--	50D3772 (USAF)	--
MIL-H-5364A (USAF)	10-16-56	MB-2A	1.72	HC-1	57D677	3600
		MB-2	1.72	H-21	53D20961	3600
		G-1	1.72	HU-1, L-19, & H-34	50D3770	1800
MIL-H-5428A*	12-14-56	D-2 (Troop)	1.72	H-19, H-37, & H-21	49D7079	--
MIL-H-18970	4-16-57	Standard "V"	1.75	H-13, L-23	MS16068 July '55	3775
MIL-H-18971	4-18-57	Standard "Y"	1.75	--	MS16069 July '55	4000

* These specifications are not available; therefore, strength could not be stated.

A shoulder harness will inherently contain a dynamic strength in excess of its static strength similar to that of lap belts; therefore, the existing 3600-pound (Type MB-2) harness should sustain the previously recommended 4000 pounds for a very short time span. The Type G-1 (1800-pound) harness is understrength and should be replaced with one of the stronger harnesses, but all harnesses of 3600-pound strength or greater are adequate. Future shoulder harness designs should be increased in width to 2.0 inches for optimum load distribution, as discussed previously, and should also be required to withstand 4000 pounds for a minimum of 0.10 second.

The strength of the inertia reel should be equal to or greater than the shoulder harness strength. All inertia reels used in U. S. Army aircraft are designed in accordance with MIL-R-8236, which specifies an ultimate static strength of 4000 pounds which is adequate as already indicated; nevertheless, it should be noted that an inertia reel's operating mechanism is subjected to a considerable shock load during decelerations. An MA-6 reel's locking gear has actually failed during an accident[5] in which an 1800-pound-strength shoulder harness was installed. Although the impact conditions were nonsurvivable, this failure does indicate that the inertia reel can fail without a corresponding shoulder harness failure.

Inertia reels should be further evaluated to determine the maximum velocity of the reel strap at the instant of automatic lock actuation. This velocity of contact would determine the maximum shock load to be expected on the reel's locking mechanism.

<u>Dynamic Strength of Restraint Systems</u>

The strength of the restraint harness alone has been considered previously; however, the seat, seat anchorages, and floor structure are equally important links in the tiedown "chain." Repeated failure of this chain in potentially survivable accidents has been discussed, but the causes of failures have not; therefore, an attempt is made in this section to discuss briefly some of the causes.

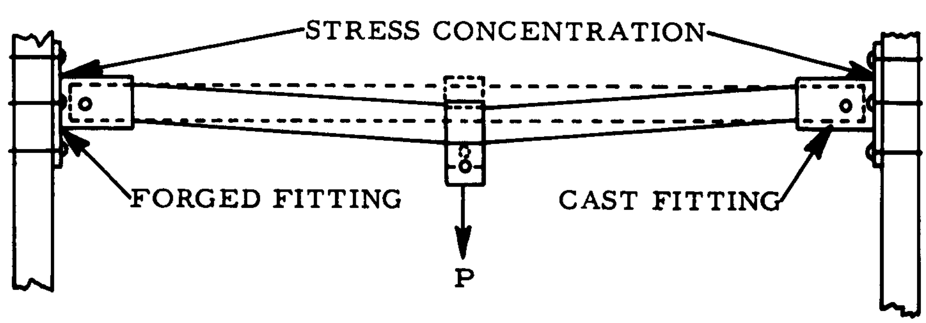
Current military specifications governing the design of restraint systems require that the system withstand the application of static loads only. Static load tests, under controlled conditions, reveal the <u>statically</u> weak links in the tiedown chain; however, the manner in which <u>dynamic</u> loads are transmitted (amplified or

attenuated) through the aircraft's structure and seat components are not revealed. The transmittal of loads can be revealed only by dynamic tests of the entire aircraft, or a structure which properly simulates the dynamic response of the aircraft, in which the system is installed.

Only dynamic tests can reveal the weak points of a restraint system, because only dynamic tests can show the advantages of using ductile materials. For example, consider two aircraft crew seats of equal weight, equal static strength, and equal geometry. Seat Number 1 would be constructed with materials of low ductility (low elongation), say less than 7 percent, while Seat Number 2 would be constructed of materials of high ductility, at least 12 percent. Dynamic tests would demonstrate the superiority of the second seat in which the higher ductility material would lengthen the crash pulse time and thereby reduce the peak loads on the seat and the occupant. This example illustrates the point that two seats, designed to equal static loads, will not behave the same when subjected to dynamic (crash) loads.

In a considerable number of accidents involving military aircraft, the initial failure in the "chain" occurs in cast materials. Although cast materials are acceptable in accordance with existing military specifications covering the design and construction of seats, anchorages, and supporting structure, it is well known that these materials are not ideal for applications requiring large elongations in areas of stress concentration.

Castings fail due to their inability to elongate or deform at stress concentration points, whereas more ductile materials elongate and redistribute load. This point can be illustrated by a simple beam loaded as shown below:



The forged fitting and the cast fitting are theoretically of identical geometry and strength; however, the elongation value of the forging would be twice that of the casting. As the load (P) is increased, the strain at the stress concentration points increases equally; however, failure will occur first in the casting because the strain exceeds its maximum elongation before that of the forging. This simple example indicates that castings should be avoided in all areas where stress concentrations exist, or where large elongations are necessary to obtain maximum strength in the remainder of the structure. A discussion of the methods used in analyzing restraint system structures for ultimate load capacity is included in Appendix I; the "limit analysis" methods indicated therein are applicable only where ductile materials are used.

The use of ductile materials in a restraint system design is also worthy of consideration from the standpoint of fracture toughness or energy-absorbing properties. A comparison of the energy-absorbing potential of various aircraft materials is included in Appendix II. If an entire restraint system is designed with materials of relatively high fracture toughness, an extra margin of safety is available during the critical milliseconds of an aircraft crash pulse. A little extra elongation in the "tiedown chain", due to the use of ductile materials, can be very important in smoothing out the peak decelerative forces acting on the aircraft's floor.

This section can be summarized by emphasizing two points:

1. Dynamic testing of restraint systems is a necessity if the system is to be relied upon to resist crash loading.

2. During the detail design phase of restraint system development, the use of high-ductility materials should be specified.

APPENDIX I. STRENGTH OF RESTRAINT SYSTEMS

An optimum restraint system would have sufficient strength to perform its required function at minimum weight. (This function is to restrain personnel from injurious contact with their environment.) Other criteria enter the evaluation of a restraint system, such as personnel comfort, ease of installation, and freedom of movement; however, the primary concern is strength. For a meaningful strength analysis, several guiding principles are helpful. These are presented below:

1. Elastic Stress Analysis

   Standard elastic stress analysis (in which stresses are kept within elastic limits and deflections kept very small) would be used to insure that no undesirable elastic deflections, permanent deformations, or fatigue failures could occur due to normal flight operational loads. Use is made of collected empirical strength data on stress concentrations, standard connections, endurance limits, etc., such as found in ANC-5 or standard textbooks; however, this type of analysis is not useful when yield limits are ignored and failure load is considered to be the primary guide.

2. Plastic Analysis

   For crash load conditions "limit analysis" concepts are frequently appropriate (References 4 and 13). With limit analysis, plastic strains are tolerated provided the strains are well below the elongation of the material. It is thus necessary to verify that sufficiently ductile materials are employed in applications subject to large strain concentrations so as to avoid the possibility of material rupture. In this regard, castings of low ductility or brittle materials generally should be avoided in highly stressed links of the "restraint chain." An idealized limit analysis, in which elastic strains are considered to be negligible in comparison with plastic strains (and hence ignored), has distinct analytical advantages; however, some caution should be exercised in applying this approach. It should be ascertained at the outset that no member has large elastic deflections

under low stress, as for example in the bending of a thin flexible beam. (Such a condition would require consideration of the elastic deformation in solving the statically indeterminate problem.) In the absence of this situation, idealized limit analysis is valid and leads to two very useful theorems:

(a) "Upper Bound Limit Load Theorem"

For any assumed "mechanism" of collapse, the calculated load is equal to or greater than the actual load causing collapse. To calculate the associated load, the yield stress (or an equivalent yield stress for flexure) is assumed at each "plastic hinge" or "plastic extensor" in the mechanism.

(b) "Lower Bound Limit Load Theorem"

For any assumed stress distribution, which satisfies static equilibrium throughout the structure and nowhere exceeds the yield stress (or an equivalent yield stress), the computed load is equal to or less than the actual collapse load. With the lower and upper bound theorems, one may bracket the actual collapse load on a given structure and thus obtain a reasonable approximation to its load-carrying capacity.

(c) Ultimate Plastic Analysis

In certain situations, particularly with redundant structures, one may even extend the limit analysis approach to a large deflection "ultimate analysis." In this latter approach, localized failures may be assumed to take place, permitting relatively large deflections and resulting in an entirely new configuration. The load capacity is then computed from the equilibrium of the new configuration. The diaphragming of a plate and the large deflection bending of a beam into a truss-type structure are examples of situations permitting this analysis. The magnitude of deflections permitted in this analysis would, of course, be limited by the allowable displacements of the restrained personnel in the given environment.

APPENDIX II. FRACTURE TOUGHNESS OF METALS

The capability of a material to resist impact loads is called "Fracture Toughness", the measure of maximum energy absorption. The following quote* describes the difference between static and energy loads:

> "Where the load is applied slowly there is a force to be resisted and the part needs stress resistance; where the load is applied suddenly there is energy to be absorbed and the part needs energy resistance, which may be the critical condition rather than the stress resistance. A material may serve well for one case and not for the other."

The ability of various materials to absorb energy loads can be measured by comparing the area enclosed by the stress-strain curves of each. Since the stress-strain relationship (as occurs up to the ultimate strength of a material) is not readily available, the following equations**can be used to approximate closely the area enclosed by the stress-strain curves:

For ductile material with a definite yield point:

$$\text{Fracture Toughness} = \frac{s_y + S_u}{2} \cdot e_u \cdot AL$$

For ductile material without a definite yield point:

$$\text{Fracture Toughness} = \frac{2}{3} s_u e_u \cdot AL$$

where,

s_u = ultimate tensile strength in psi

s_y = yield tensile strength in psi

e_u = ultimate strain in inches per inch

A = area of material cross section in sq. inch

L = length of material absorbing energy

---

* Draffin, J. O., and Collins, W. L., Statics and Strength of Materials, The Ronald Press Company, New York, 1950, p. 138.

** Seely, F. B., M. S., Resistance of Materials, John Wiley & Sons, Inc., New York, February 1949, p. 315.

These equations are used to calculate the fracture toughness of several materials, as shown in the tabulation on the following page.

The properties of 2014 and 2024 aluminum alloys are taken from pages 72, 73, and 125 of Reynolds Metal Company's "Aluminum Data Book" since the -T3 and -T4 tempers of both were not available in ANC-5, "Strength of Metal Aircraft Elements." All other material properties are taken from the ANC-5 Handbook.

The materials in Table 4 were all selected for their high-energy-absorbing qualities. The elongation of the selected castings is much higher than that of other castings, which in some cases are as low as 1.5 percent, but it can be seen that even the best castings are not as efficient as wrought materials for absorbing energy loads.

TABLE 4
FRACTURE TOUGHNESS COMPARISON OF SEVERAL METALS

FRACTURE TOUGHNESS COMPARISON OF SEVERAL METALS

Material	Form	Temper	Tensile Strength Ult. Ksi	Tensile Strength Yield Ksi	Elongation Per-cent	Toughness In.-lb.	Density Lb. per cu. in.	Toughness/Density In.-lb. per lb.	Approx. Cost Dollars per lb.
Al. Alloys:									
195	Sand casting	-T4	29*	13	6	1160	.102	11,400	0.90
200	Sand casting	-T4	42*	22	12	3360	.093	36,200	0.90
2014	Sheet	-T3	57	36	15	5700	.101	56,400	0.90
2014	Extrusion	-T4	50	30	12	4000	.101	39,600	1.20
2024	Sheet	-T3	64	42	15	6400	.100	64,000	0.95
2024	Extrusion	-T4	60	40	10	4000	.100	40,000	1.25
Steels:									
1025	All wrought forms	Normalized	55	36	22	10,000	.283	35,300	0.20
4130	All wrought forms	Normalized	90	70	17	13,600	.283	48,000	0.49
4130	All wrought forms	150,000	150	132	18	25,400	.283	89,800	0.50
301 Stainless	Sheet	Annealed	75	30	50	26,200	.286	91,700	1.45
301 Stainless	Sheet	1/4 Hard	125	75	25	25,000	.286	87,500	1.50

* This is the minimum guaranteed strength of a separately cast test bar. The mechanical properties of production castings may be as low as 75 percent of this value.

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ALFSEE	2
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APGC(PGAPI)	1
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1. Personnel Restraint Systems Study - Basic Concepts
2. Contract DA-44-177-TC-802

Aviation Crash Injury Research, Phoenix, Arizona, PERSONNEL RESTRAINT SYSTEMS STUDY - BASIC CONCEPTS, December 1962, J. L. Haley, Jr. and J. P. Avery, Ph. D., TCREC Technical Report No. 62-94, December 1962, 56 pp. (Contract DA-44-177-TC-802) USATRECOM Task 9R95-20-001-01 (Unclassified Report)

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